(BSP May 17, 2004)

Narrow Gap Improved-Electroslag Welding (NGI-ESW) Procedure

The NGI-ESW procedure may be used for groove welds in bridge members and member components up to 100 millimeters thick subject to the following requirements:

In members subject to applied tensile stress under any loading condition, the NGI-ESW procedure may be used provided:

1. The NGI-ESW procedure is qualified in accordance with the AASHTO/AWS D1.5M/D1.5:2002 Section 5.13 and 5.14 procedure qualification tests, and satisfies the following criteria:

    a. Weld Metal: 27J at –20C.

    b. HAZ: 20J at 4C.

2. The application is limited to AASHTO temperature Zone I and Zone II.

The NGI-ESW procedure qualified for welding of tension members will be considered as also qualified for compression members without additional testing.

The NGI-ESW procedure shall not be used for fracture-critical members.

NGI-ESW shall be used only with AASHTO M 270M Grades 250, 345 and 345W, and ASTM A 709M Grades 250, 345, and 345W steel.

Oscillation is not permitted in the NGI-ESW procedure, unless qualified by test and approved by the Engineer.

Preheat is not required for NGI-ESW.

Welding Procedure Specification (WPS) Submittal

The welding procedure specification submittal for NGI-ESW shall include, but not be limited to, the following:

1. Process type (eg. NGI-ESW).

2. Guide design (eg. wing or web type), number of wires, and material used for the guide (eg. AISI 1008 steel).

3. Flux type, including the amount added initially, and the subsequent flux feed rate.

4. Joint details, such as the joint gap dimension and the plate thickness(es).

5. Base metal.

6. AWS electrode designation, composition, diameter, manufacturer, product name, type (eg. tubular metal power cored).

7. Wire feed speed.

8. Type and polarity of current (eg. DC electrode positive (DCEP)).

9. Current and voltage.

10. Power source characteristics (eg. constant voltage and 100 percent duty cycle rating at 1500 amps).

11. Details of water-cooled shoes such as reinforcement groove dimensions and coolant flow rate.

12. Type of sealing material used to prevent slag run-outs.

13. Accessories used within the weld zone (eg. type of insulating tape used to brace the consumable guide).

Qualification Testing

The Contractor shall provide the opportunity for Contracting Agency representatives and NCI-ESW development personnel from the Oregon Graduate Institute of Science and Technology or the equipment manufacturer to witness all qualification testing.

Toughness Revisions to AASHTO/AWS D1.5M/D1.5:2002 Table 4.2

To utilize NGI-ESW, the following revisions to Table 4.2 are required:

Non-Tension Members

Grade 250	NGI-ESW = 27J at –20C	Zones I & II
Grade 345	NGI-ESW = 27J at –20C	Zones I & II
Grade 345W	NGI-ESW = 27J at –20C	Zones I & II

Tension Members

Grade 250	NGI-ESW = 27J at –20C	Zones I & II
Grade 345	NGI-ESW = 27J at –20C	Zones I & II
Grade 345W	NGI-ESW = 27J at –20C	Zones I & II

HAZ of Tension and Reversal Members

CVN toughness of the heat-affected zones (on both sides of the narrow gap improved-electroslag weld) shall meet or exceed 20J at 4C.

Electrode

Electrode wire for NGI-ESW shall be FES70-EWTX with a maximum diameter of 3/32 inch. Electrode wire shall conform to the following chemistry requirements:

Element	Percent by Mass (maximum unless range is specified)
C	0.03
Mn	1.0 – 1.4
Si	0.3 – 0,45

Ni	2.7 – 3.2
Mo	0.25 – 0.45
Ti	0.01 – 0.04
Al	0.01
S	0.015
P	0.015
V	0.005
B	0.0005
Cu	0.01
Nb	0.01

The electrode wire chemistry shall be evaluated by a melt button of the electrode, analyzed by spectrometer. If the spectrometer accuracy for low carbon and sulfur content is not adequate, additional analyzing of these elements may be accomplished by other methods.

The electrode shall be analyzed for diffusible hydrogen by the GMAW process shielded by 100 percent argon at 40 – 50 CFH. The maximum diffusible hydrogen shall be 4 ml per 100 grams.

The electrode wire material shall have a tensile strength of 485 to 610 MPa, a minimum yield strength of 354 MPa, a minimum elongation of 22 percent, and minimum charpy V-notch toughness of 27 J at –20C.

Electrode wire shall be dry and free of contamination from dirt, grease, rust and other foreign material. Electrodes shall be received in undamaged moisture-resistant packages. Electrodes shall be protected against contamination and damage during shipment and storage. Electrodes in packages damaged during shipment and storage shall be discarded and not used. Electrode packages shall remain effectively sealed against moisture until the electrode is required for use. When removed fro the protective packaging and installed on the welding machines, care shall be taken to protect the electrodes from deterioration and damage. When welding is suspended for more than eight hours, th electrodes shall be removed from the welding machines and stored in accordance with the electrode manufacturer's recommendations.

Consumable Guides

The consumable guide chemical composition shall conform to the following requirements:

Element	Percent by Mass
C	0.06
Mn	1.0
Si	0.6
Cr	0.1
Ni	0.23
Mo	0.03
Al	0.05
Cu	0.05
Ti	0.05

S	0.02
P	0.02

Consumable guides shall be dry and free of contamination from dirt, grease, rust and other foreign material, and shall be in suitable condition for use. Consumable guides shall be received in undamaged moisture-resistant packages. Electrodes shall be protected against contamination and damage during shipment and storage. After removal from the package, the consumable guides shall be protected and stored to remain free of rust, moisture, and other contaminants that may affect welding properties.

The distance from the edge of the consumable guide to the surface of the weld plate shall be not less than six millimeters nor greater than 22 millimeters. The distance from the center of the electrode wire to the surface of the weld plate shall be not less than 13 millimeters nor greater than 38 millimeters. For consumable guides designed for multiple electrodes, the electrode separation (center to center) shall not exceed 50 millimeters.

The electrode wire passage shall be a diameter or width of 2.8 millimeters $\pm$ 0.2 millimeters to allow proper current transfer from the electrode wire.

Configurations of consumable guides for NGI-ESW shall be in accordance with Figure R1 as shown in Plans, or equivalent, subject to successful qualification testing.

The purposes of the wing (single wire) and web (dual wire) guide arrangements are to: (1) reduce solidification cracking susceptibility by distributing the heat across the weld pool and increase the weld w/d (width/depth) ratio, (2) increase current-carrying capacity of the electrode-guide assembly, and (3) stiffen the guide assembly.

The consumable guides shown in Figure R1 (A through E) are suggested designs for equal-thickness butt joints and for transition thickness butt joints. For example, the designs shown in Figures R1 A and B may be used for ESW with single electrode arrangements for either 32 millimeter equal-thickness butt joints, or 32 to 50 millimeter transition-thickness butt joints. In a second example, the designs shown in Figures R1 A, C and D may be used for 50 millimeter equal-thickness butt joints.

Root Face and Adjacent Faying Surface Preparation

Surfaces of the plate within 25 millimeters of the weld joint, and all surfaces on which weld metal will be deposited, shall be free of mill scale, corrosion and other contaminants. The groove preparation for NGI-ESW shall be square with a root opening of 20 millimeters $\pm$ 3 millimeters.

Starting Sump and Run-off Tabs

The starting sump and run-off tab area shall have at least the same dimensions as those used for procedure qualification. The sump depth shall be not less than 75 millimeters. Tack welds joining steel tabs and steel sumps to the plates shall be placed within the joint being welded in order to completely remelt and incorporate the tack welds during the subsequent ESW process. If tack welds on permanent base metal are not remelted, the tack

welds, and a three millimeter deep layer of the base metal under the tack welds, shall be removed to remove the heat-affected zone. Grade 345W sumps and run-off tabs shall be used for welding Grade 345W material. Grade 345 or 345W sumps and run-off tabs may be used for welding Grade 345 and Grade 250 material. Grade 250 sumps and run-off tabs shall be used only for welding Grade 250 material.

Flux Basicity and Condition

The basicity of flux shall be neutral to ensure uniform weld metal composition throughout the length of weld. Fused fluxes will be required. Flux shall be dry and free of contamination from dirt, grease, mill scale, or other foreign material. Flux shall be received in moisture-resistant packaging that can be stored under normal conditions for at least six months without affecting the welding characteristics or weld properties of the flux. Flux supplied by the manufacturer in a sealed package may be dispensed for use without drying if that use occurs within four hours of opening the package. Flux that has been exposed for more than four hours shall be conditioned at 120C for at least two hours prior to welding, or as recommended by the manufacturer, and stored at the same temperature until dispensed for use. Flux from packages damaged in transit or in handling shall be discarded. Flux that has been wet shall not be used.

Insulators

Insulators shall be kept dry and free of contamination from dirt, grease and other foreign material. Insulators shall be stored in sealed packages or according to the insulator manufacturer's guidelines. The material composition of the insulators shall be compatible with the flux for NGI-ESW and shall not affect mechanical properties of the weld.

Retaining Shoes

The portions of retaining shoes in contact with molten metal and base metal adjacent to the weld shall be (1) made of copper and (2) water cooled. Copper shoes shall fit tightly on the plate surface to prevent slag leakage. Only dry refractory material shall be used to fill shoe-to-plate gaps. Water-based sealers shall be limited to reinforcing previously placed tapes along the outside edges of the shoes to prevent slag leackage.

Procedure for Electroslag Welding

Using the NGI-ESW procedure, welds shall be started in such a manner as to permit sufficient heat buildup for complete fusion of the weld metal to the groove faces of the joint before the weld leaves the sump. Restarts will not be allowed between the end of the weld and 75 millimeters from the beginning of the weld. If the weld cannot be completed, it shall be removed to at least 3 millimeters beyond the widest part of the weld nugget and rewelded.

Flux Additions and Slag Depth Control

After the NGI-ESW process has been established, flux additions shall be continuously regulated using an automatic feeding device. The slag pool depth qualified in the PQR shall be maintained. Slag depletion shall be monitored through current fluctuations on a continuous current and voltage chart recorder (or similar recording equipment). Alternatively, this process may be automated.

WPS Pretest and WPS Qualification

A WPS pretest is a WPS qualification test in accordance with AASHTO/AWS D1.5M/D1.5:2002 Section 5.12 and Figure 5.1 by someone other than the Contractor, but used by the Contractor as a basis for preparing WPS's. WPS pretests will not be permitted for NGI-ESW welds subject to tensile stress.

AASHTO/AWS D1.5M/D1.5:2002 Figure 5.2 shall be used for NGI-ESW qualification. If transition joints between thick and thin members are made, the PQT shall be conducted on the thinner of the two plates.

Inspection

Testing of welds made by NGI-ESW for compression members shall be in accordance with AASHTO/AWS D1.5M/D1.5:2002 Section 6. All welds deposited by NGI-ESW subjected to applied tensile stress shall be 100 percent tested using both radiographic and ultrasonic methods, and evaluated in accordance with AASHTO/AWS D1.5M/D1.5:2002.

Repair Welding

Repair welding of electroslag welds deposited on compression members shall be in accordance with AASHTO/AWS D1.5M/D1.5:2002, except as otherwise noted. Repair of NGI-ESW welds carrying applied tensile stresses shall be conducted in accordance with AASHTO/AWS D1.5M/D1.5:2002 Section 12.17 with the following exception.

> Welds having defects prohibited by AASHTO/AWS D1.5M/D1.5:2002 Section 6.26 shall be repared in accordance with an approved procedure using a qualified weld process, or the entire weld shall be removed at least three millimeters beyond the widest part of the weld nugget and rewelded. If the depth of detectable cracks is within six millimeters of the weld centerline and if the cracking is longer than 15 percent of the weld length (not including the run-on and run-off tabs), the weld shall not be repaired, but instead shall be removed to at least three millimeters beyond the widest part of the weld nugget and shall be rewelded. The widest part of the weld may be estimated by cutting 13 millimeters beyond the visible reinforcement for tension members.

Weld Specimens, Type and Number of Tests for NGI-ESW

Weld metal specimens deposited by NGI-ESW and subject to applied tensile stress shall be prepared for mechanical testing in accordance with Figure R2 as shown in the Plans, and AASHTO/AWS D1.5M/D1.5:2002 Table 5.5, plus additional CVN testing of the heat-affected zone (HAZ).

HAZ Specimens, Type and Number of Tests for NGI-ESW

For all compression members including NGI-ESW of compression members, CVN testing of the HAZ is not required. However, for welds deposited by NGI-ESW on tension members, additional CVN tests of the HAZ shall be performed to qualify the process. The CVN tests for the HAZ shall be the following:

1. Five specimens shall be removed from the quarter-thickness section of the HAZ on each side of the procedure qualification welded joint in accordance with Figures R2 and R3 as shown in the Plans.

2. The weld fusion line shall be revealed by etching the transverse-to-weld section.

3. The notch location shall be in the base metal within 1.5 millimeters from the weld fusion line. If the weld curvature does not permit the entire notch to be placed within 1.5 millimeters from the fusion line, then one end of the notch shall be placed on the fusion line while the remaining portion of the notch extends away from the fusion line into the base metal.

If different grades of steel such as 250 and 345 or 345 and 345W are joined by NGI-ESW, the procedure qualification tests shall be conducted on the same two grades of steel. If transition joints between thick and thin members are made, the WPS shall be conducted on the same joint preparation (having the same thicknesses and joint transition slope). The heat affected zone CVN toughness specimens shall be extracted from both sides of the transition joint.

Test Results Required for NGI-ESW

Weld Metal

Eight specimens at mid-thickness location of the weld center shall be tested as shown in AASHTO/AWS D1.5M/D1.5:2002 Table 5.5. The highest and lowest values shall be discarded and the remaining six values shall be averaged. For tests to be successful, the average of the remaining six CVN test values shall meet or exceed the minimum energy value of 27J at –20C for welds subject to applied tensile stress. No more than two of the remaining six specimens may have an impact energy value less than the minimum specified, and none of the remaining six specimens shall have an impact energy value less than 2/3 of the minimum specified. If the NGI-ESW process is used for a compression member, the requirements are the same as those for conventional ESW as specified in AASHTO/AWS D1.5M/D1.5:2002 Table 4.2.

HAZ

For CVN toughness determination in welds carrying applied tensile stress, five specimens taken at the quarter-thickness location of the weld, in accordance with Figure R2 as shown in the Plans, shall be tested. The highest and lowest values shall be disregarded and the remaining three values shall be averaged. For tests to be successful, the average of the remaining three CVN test values shall meet or exceed the minimum CVN energy values of 20J at 4C. No more than one of the three remaining specimens shall have an impact energy value less than the minimum specified and none of the three remaining specimens shall have a value less than 2/3 of the minimum specified value.

References

The following documents are listed as reference for qualification testing and production welding:

D1.5 Bridge Welding Code Proposed Revisions to Include Narrow-Gap Improved Electroslag Welding

Procedural Information on Narrow-Gap Improved Electroslag Welding

Report No. FHWA-SA-96-050

Training Manual for Narrow-Gap Improved Electroslag Welding
A Step-by-Step Presentation of Basic Skills Required for Assembly and Welding
Report No. FHWA-SA-96-051

Process Operational Guide for Narrow-Gap Improved Electroslag Welding
Procedural Information on Narrow-Gap Improved Electroslag Welding
Report No. FHWA-SA-96-052

Technical Information Guide for Narrow-Gap Improved Electroslag Welding
Metallurgical Background for Narrow-Gap Improved Electroslag Welding Procedure
Report No. FHWA-SA-96-053

In the event of conflicts between the references listed above and this Special Provision, this Special Provision shall govern.